Engineering Physics 1
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Module-02
Lecture-01
Introduction

I am M K Srivastav, the Department of Physics, IIT Roorkee. This is the first lecture for the four lecture series on Acoustics.

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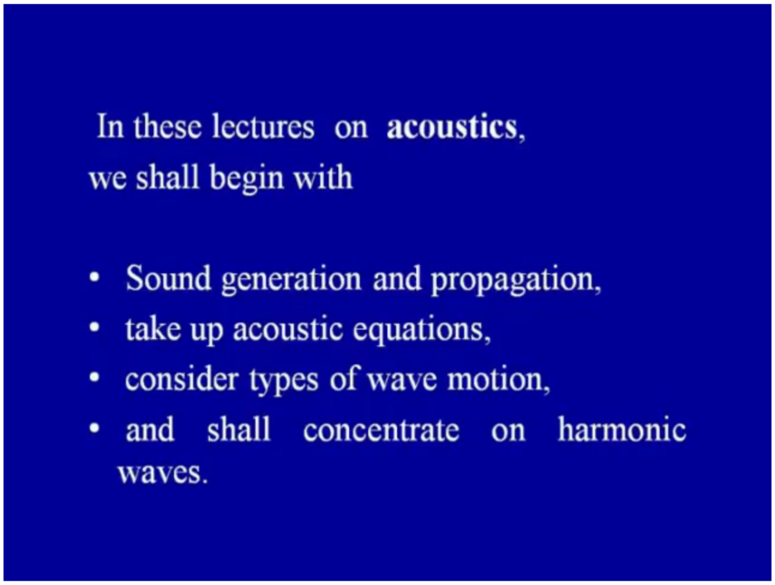

In these lectures on Acoustics, We shall begin with sound generation and propagation, take up caustic equations, consider types of wave motion and shall concentrate on harmonic waves.

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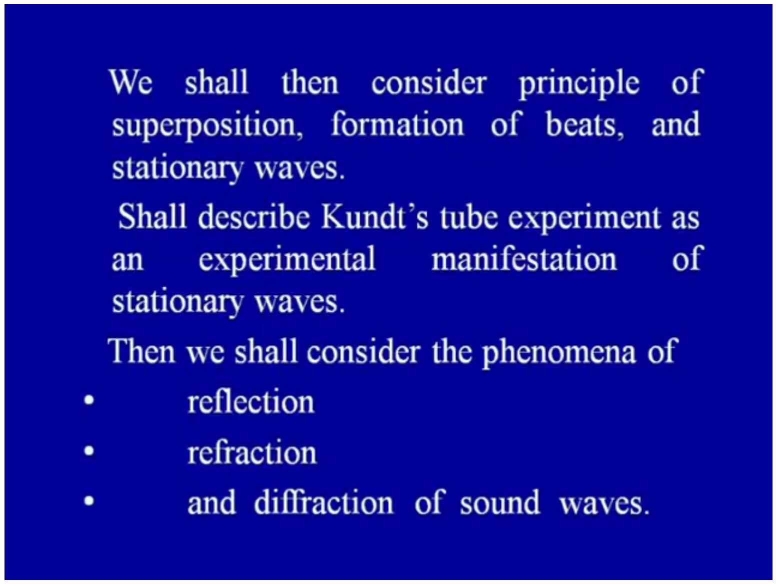

We shall then consider principle of superposition, formation of beats and stationary waves. Shall describe, Kundt's tube experiment as an experimental manifestation of the stationary waves; Then, we shall consider the phenomena of reflection, refraction and diffraction of sound waves.

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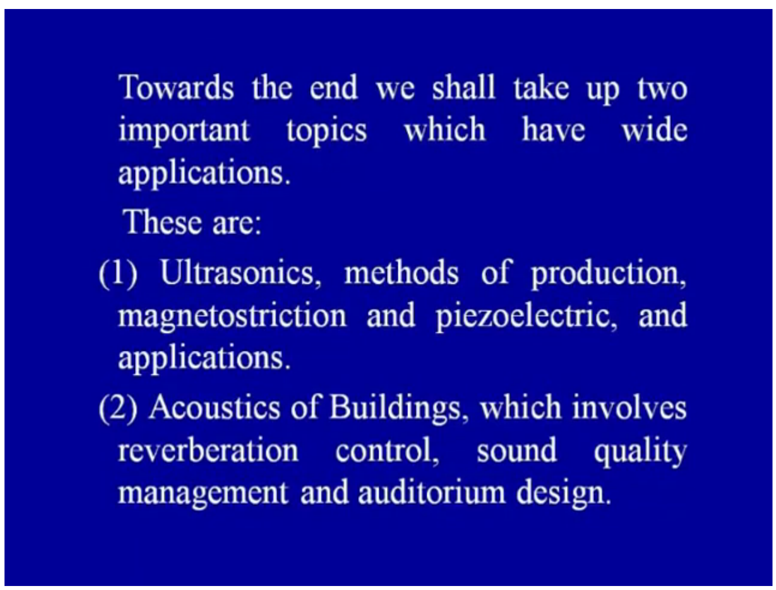

Towards the end of the series, we shall take up two more important topics which have wide applications. These are: Ultrasonics, their methods of production which are based on magnetostriction and piezoelectric effects and then the applications of ultrasonics. Number 2: the Acoustics of Buildings which involves reverberation control, sound quality management and auditorium design. Let us begin. The Acoustics is a disciplined, extremely broad in scope.

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Literally covering waves and vibrations in all media at all frequencies, but a wide range and at all intensities; primarily, it is a matter of communication.

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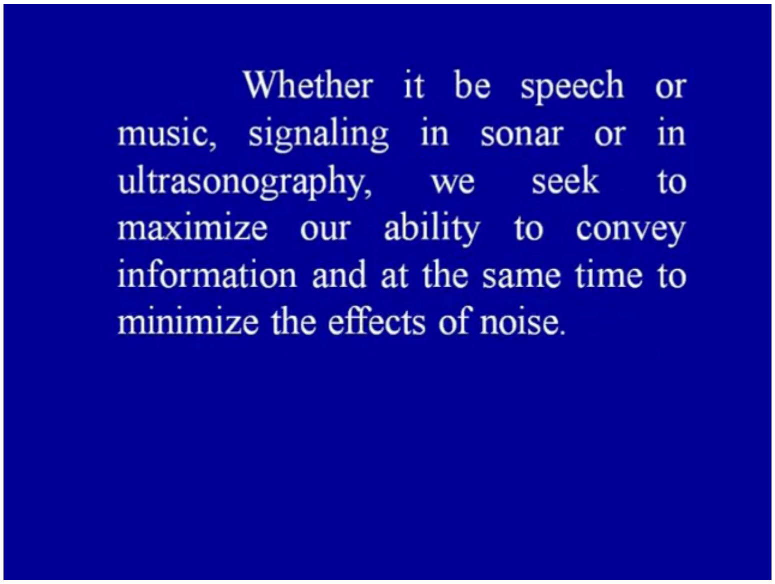

Whether it be speech or music signaling and sonar or ultrasonography, we seek to maximize our ability to convey permission and at the same time to minimize the effects of noise external or internal.

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Modern acoustics now encompasses the realm of ultrasonics and infrasonics, in addition to the audio range as a result of applications in material science, medicine, dentistry, oceanology, marine navigation, oceanology, okay communications, petroleum and mineral prospecting and music and voice synthesis.

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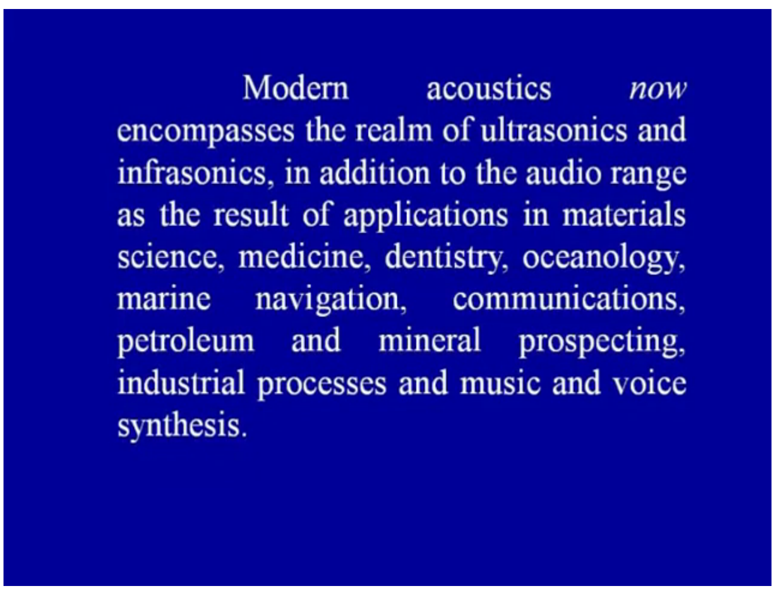

Let us consider the sound generation and propagation. You see, sound is a mechanical disturbance. Sound waves are mechanical waves. They travel through an elastic medium at a speed which is a characteristic of that medium. It is essentially a wave phenomena, as in the case of a light beam.

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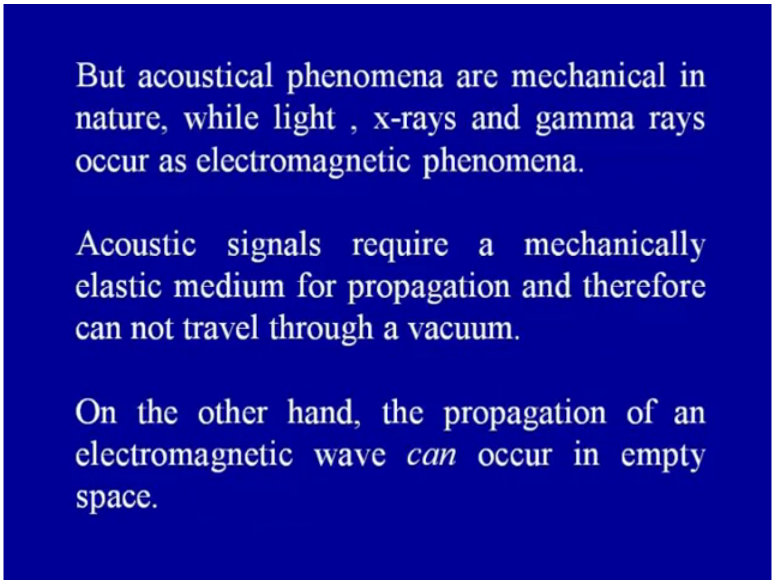

But Acoustics phenomena are mechanical in nature. The wide, the particles of the medium vibrate, while light x-rays, gamma rays, etcetera, they occur as electromagnetic phenomena. Acoustics signals require a mechanically elastic medium. See, this is a very important the medium has to be elastic. Elasticity controls the propagation so a mechanically last medium is required for propagation.

And therefore sound cannot travel through a vacuum. On the other hand, the propagation of an electromagnetic wave as we know can occur even in empty space.

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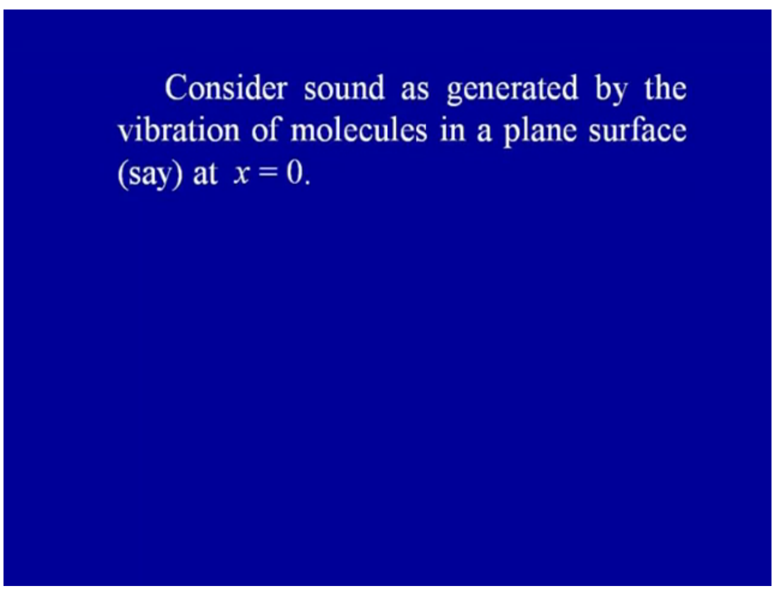

Consider sound as generated by the vibration of molecules in a plane surface. Saying at x = 0, it could be a stretched membrane; just a plain sheet placed at x = 0.

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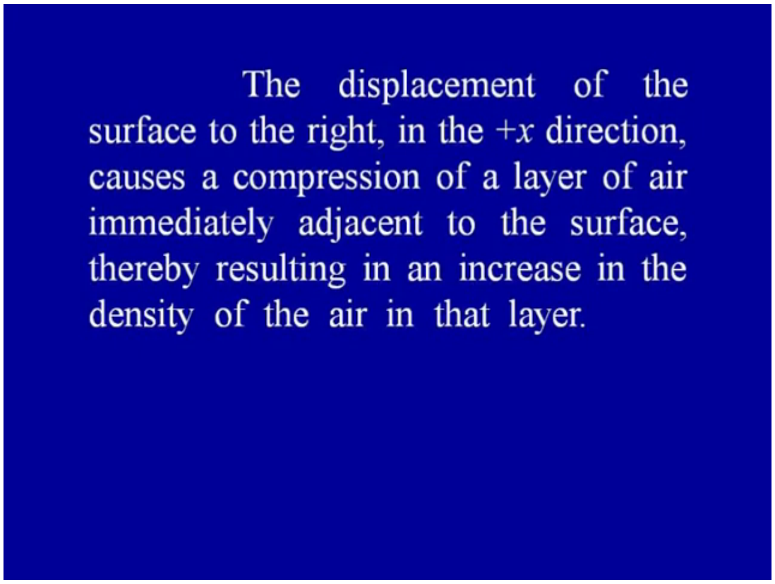

The displacement of the surface to the right as a result of vibrations in the positive direction causes the compression of a layer of air immediately adjacent to the surface, thereby, resulting in an increase in the density of the air, in that layer which is touching the surface.

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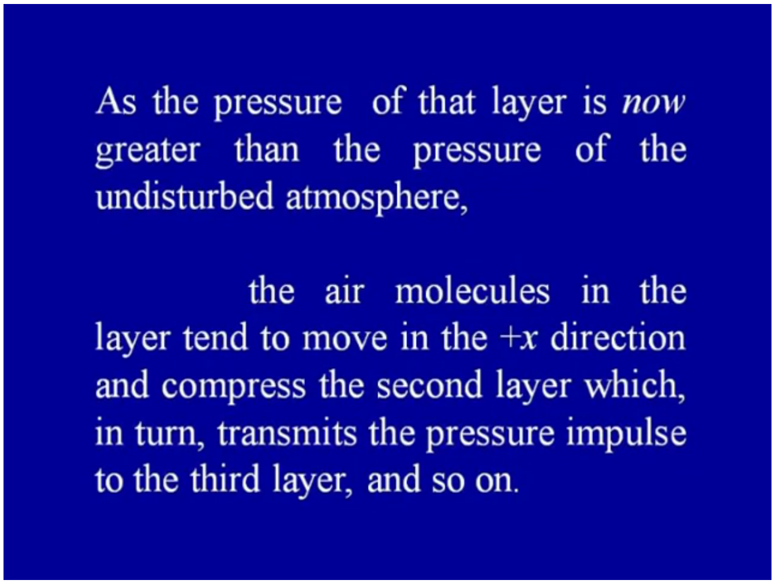

As the pressure of that layer is now greater than the pressure of the undisturbed atmosphere, the air molecules in the layer tend to move in the positive x direction and compress the second layer which in time transmits the pressure impulse to the third layer and so on.

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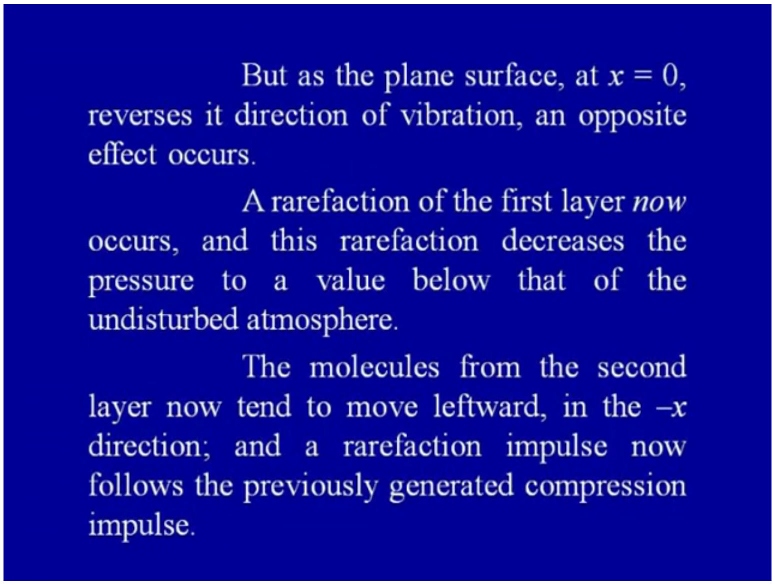

But at the plane surface at x = 0, reverses its direction of vibration, after half a cycle of vibration and opposite effect occurs. A reflection of the first layer now occurs and this reflection decreases the pressures to a value below that of the undisturbed atmosphere, the molecules from the second layer now tend to move left wards and in the negative x direction. And a rarefaction impulse now follows the previously generated compression impulse.

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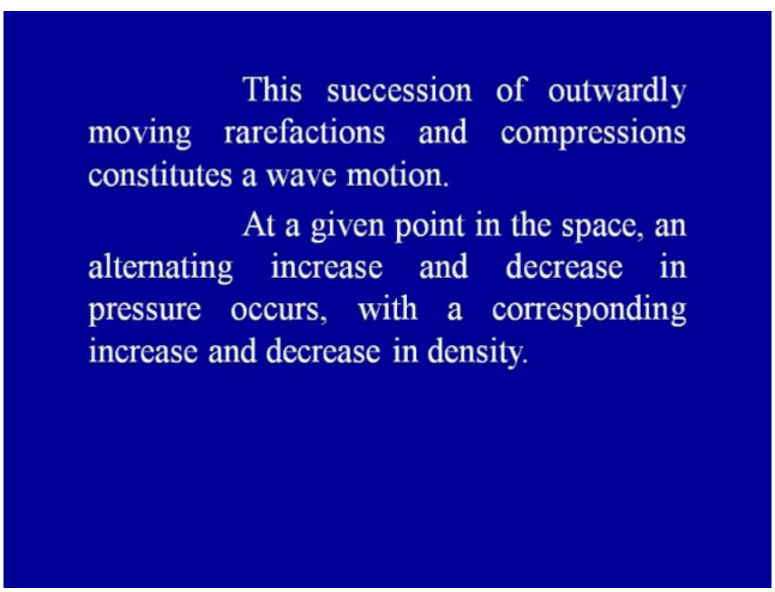

Now this succession of outwardly moving rarefractions and compressions constitutes a wave at a given point in the space. And alternating increase in decreasing pressure leading to the corresponding increase and decrease in density occurs.

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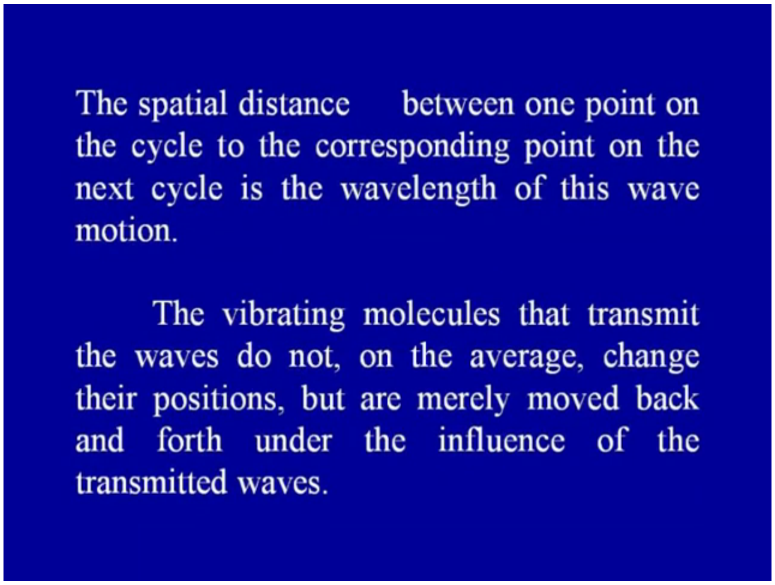

The spatial distance between and one point on the cycle to the corresponding point on the next cycle is the wave length of this wave motion. This is really the distance which the wave travels during the time the particle includes one complete vibration. The vibrating molecules that transmits the waves do not on the average, change their positions but are merely moved back and forth under the influence of the transmitted waves.

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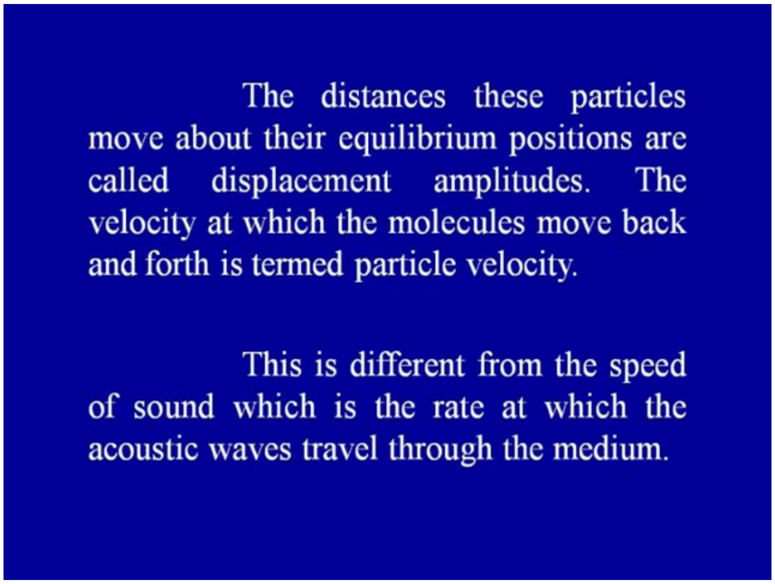

The distances these particles move about the equilibrium positions are called displacement amplitudes. Amplitude with the maximum displacement which a molecule of atmosphere suffers, when a wave is passing through, the velocity at which the molecules move back and forth about their mean position is termed particle velocity. If it is velocity, this is different from the speed of sound which is the rate at which the acoustic waves travel through the medium.

That is the characteristic of the medium. The properties of the medium determine the rate at which the sound travels in the medium.

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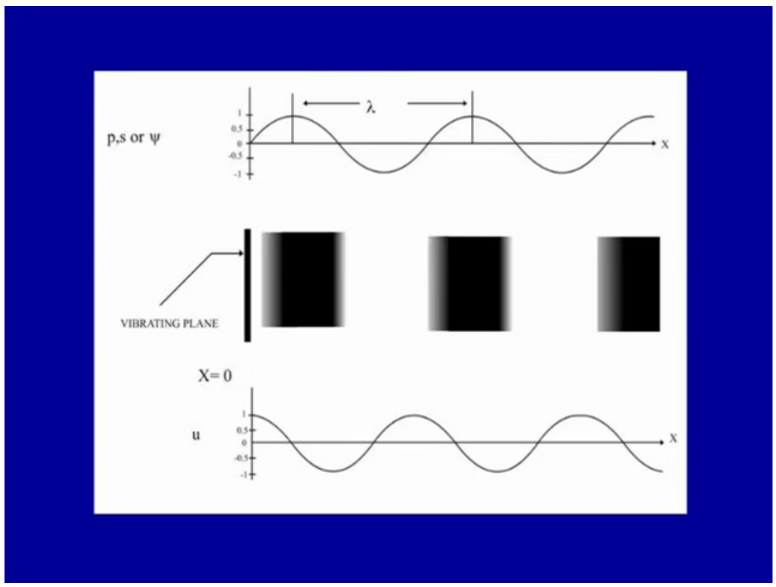

Consider this picture. It has three parts: the central portion dealing with the compression and rarefactions and then, there is a variation, density, pressure, amplitudes, the distance and in the bottom where the variation of the particle velocity is given.

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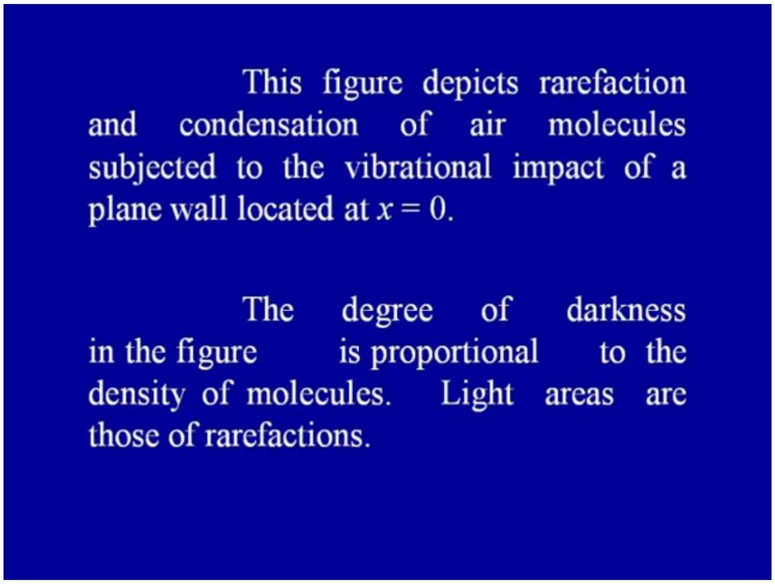

So as I said, this figure depicts refraction and condensation of air molecules subjected to the vibrational impact of a plane wall located at x=0. This plane wall could be ascetic sheet it any vibrating sheet, the degree of darkness in the figure is proportional to the density of molecules is a measure of the density of molecules. Light areas in the figure are those of rarefactions.

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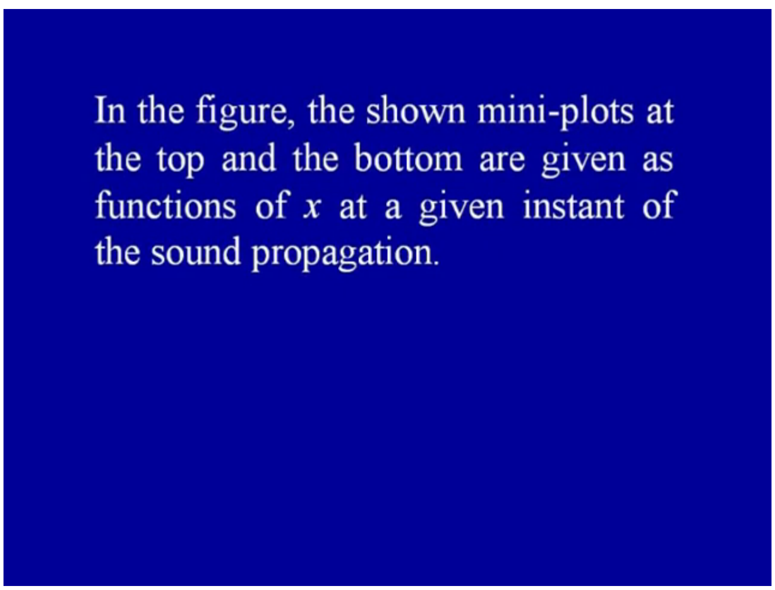

In the figure as I said the shown mini plots at the top and the bottom are given as functions of x. Remember, the propagation is along the x axis. So, as a function of x at a given instant of sound propagation at a given instant of time t.

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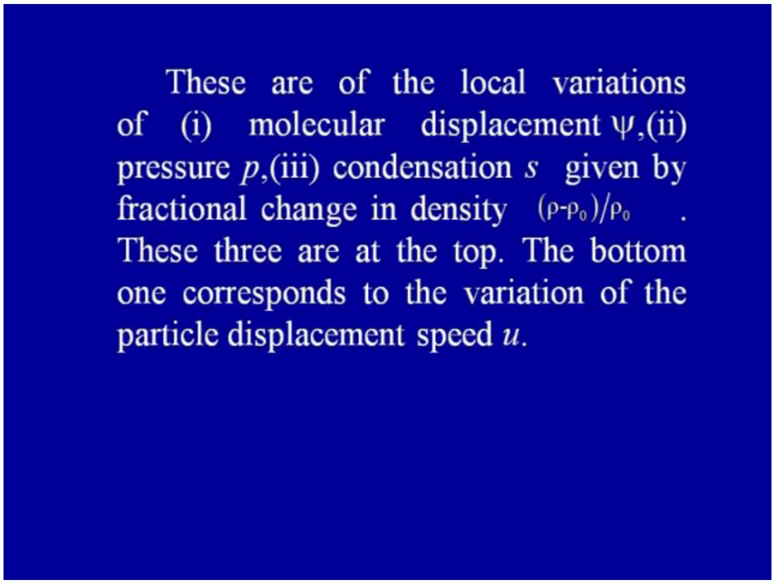

These are of the local variations of molecular displacements Phi, changes and pressure P condensation s given by fractional change in density, Rho - Rho 0 upon Rho 0. These three are at the top the bottom one corresponds to the variation of the particle displacement speed, just note the phase difference between the variations shown on the top the variations of the particle displacement the variation of pressure.

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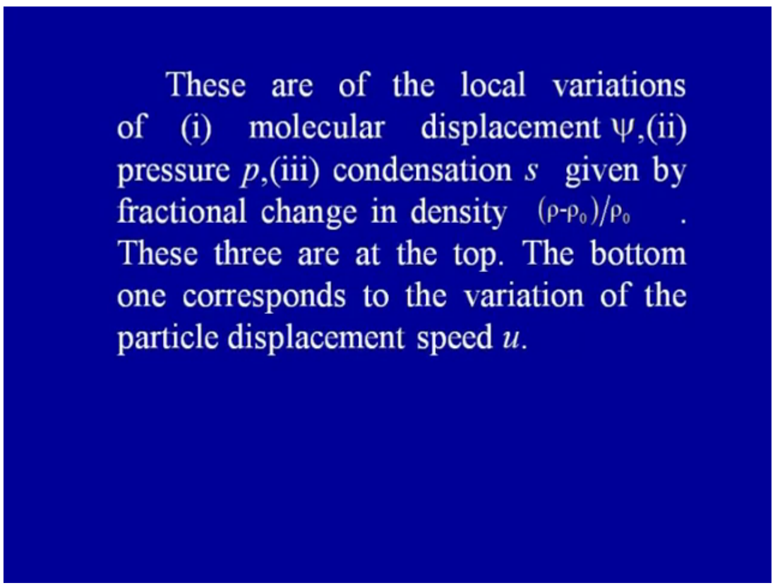

And the variation of condensation on one side, compared to the variation of the particle displacement speed u shown at the bottom. There is a phase difference of a quarter vibrations, PI by 2. You see when the molecular displacement is at maximum, the pressure change is maximum correspondingly the density changes maximum at that instant the particle displacement speed is 0.

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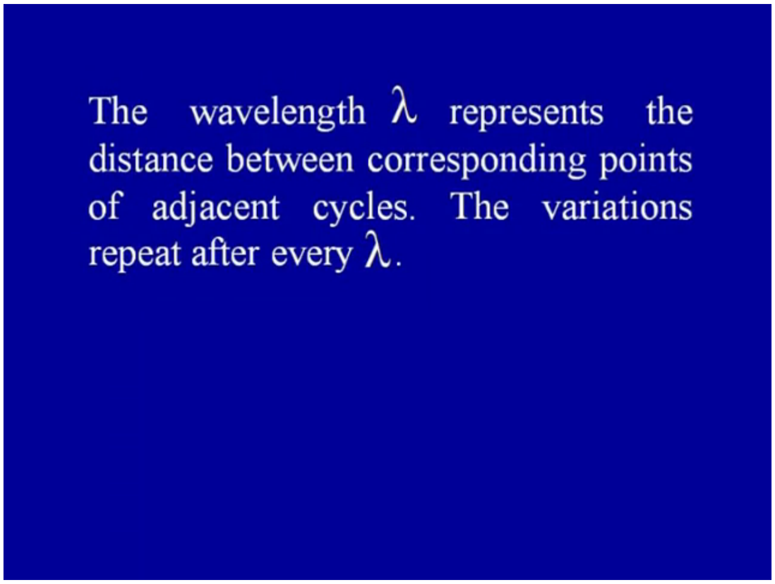

The wavelength lambda represents the distance between corresponding points of adjacent cycles; the variation repeats after every lambda. The lambda barely represents the space periodicity.

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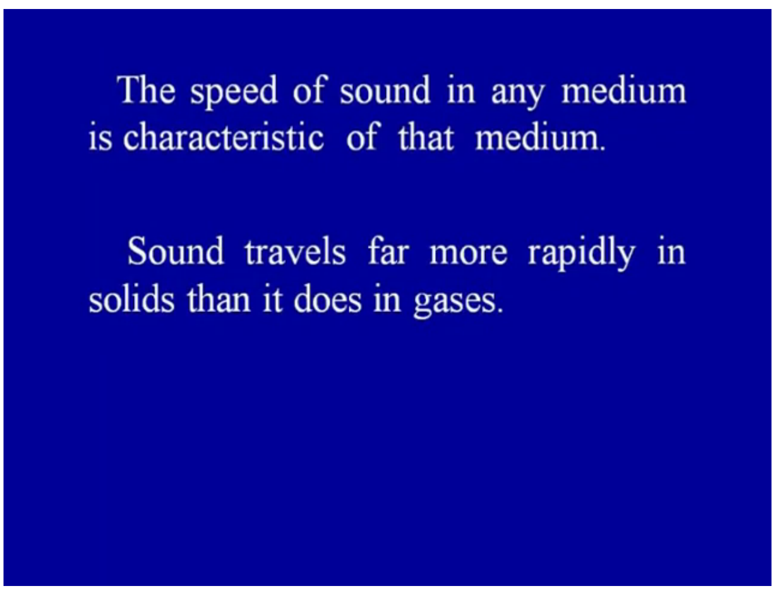

The speed of sound in any medium is characteristic of that medium as I said earlier. Sound travels far more rapidly in solids than it does in gases, a temperature of 20 degrees centigrade sound moves at the rate of 344 meters per second through air at a normal atmospheric pressure of 760 millimeters of mercury.

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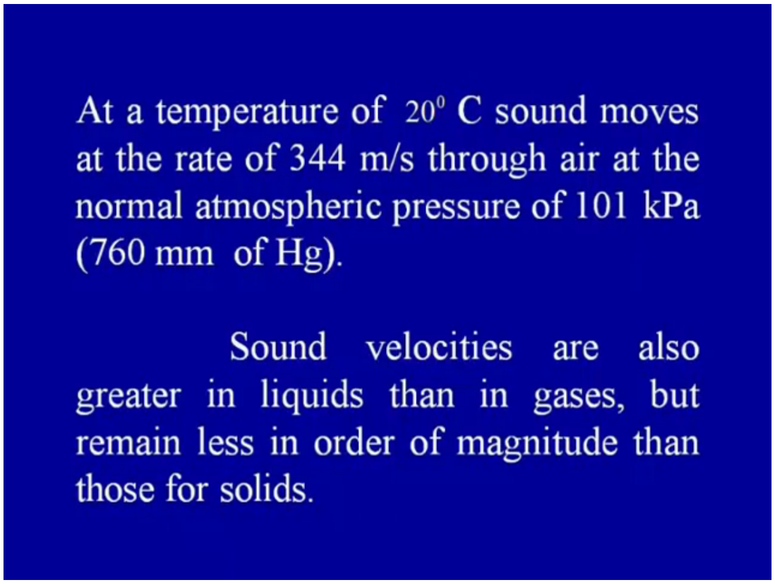

Sound velocities are also greater in liquids than in gases, but remain less in order of magnitude than those for solids.

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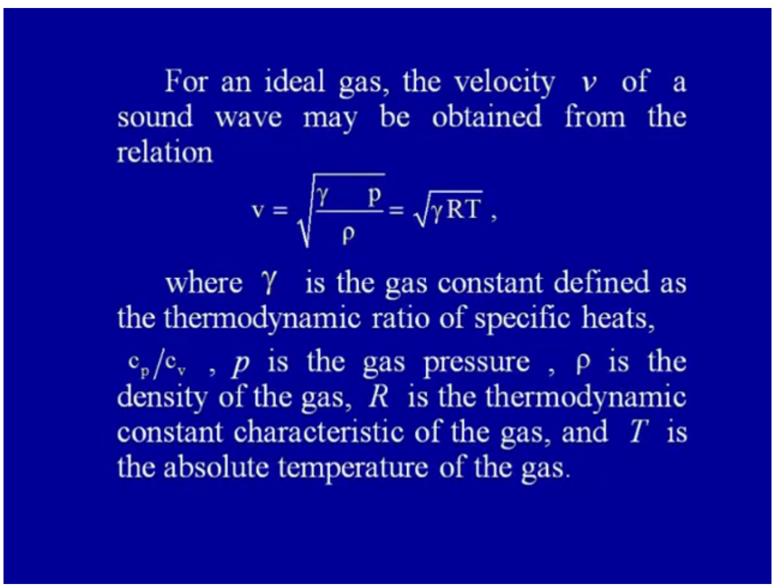

For an ideal gas the velocity v of a sound wave may be obtained from the relation v = the square root of gamma times pressure upon the density which is = the square root of gamma times R into capital T where gamma is the gas constant defined as the thermodynamic ratio specific heat cp upon cv, p is the gas pressure Rho is the density of the gas R is the thermodynamic constant characteristic of the gas.

And capital T is the absolute temperature of the gas. One thing should be noted: at a constant temperature, the velocity is not affected by changes in pressure. The reason is pressure and the density; they change in the same way. Actually, but pressure and density, they are proportional to each other at a constant temperature. This is the well-known Boyle's law.

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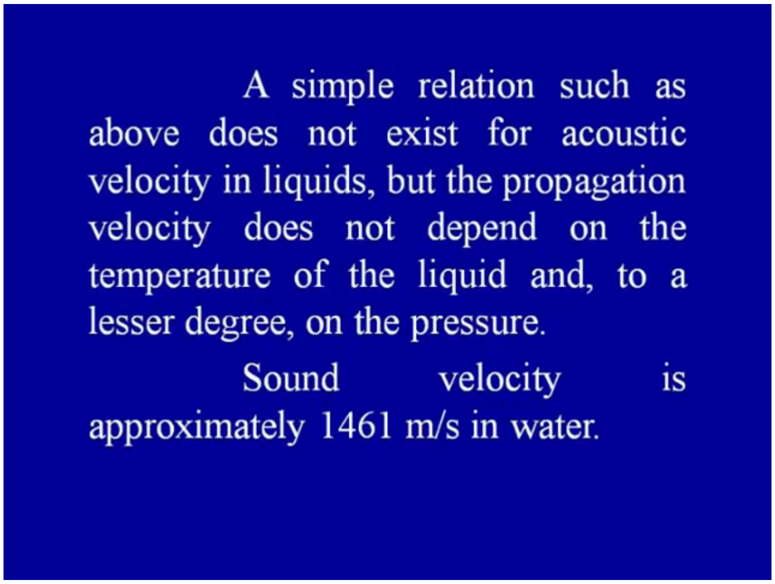

A simple relation such as the above somehow does not exist for acoustic velocity in liquids. But we know that the propagation velocity does not depend on the temperature of the liquid and to a lesser degree on the pressure. Some velocity is approximately 1461 meters per second in water.

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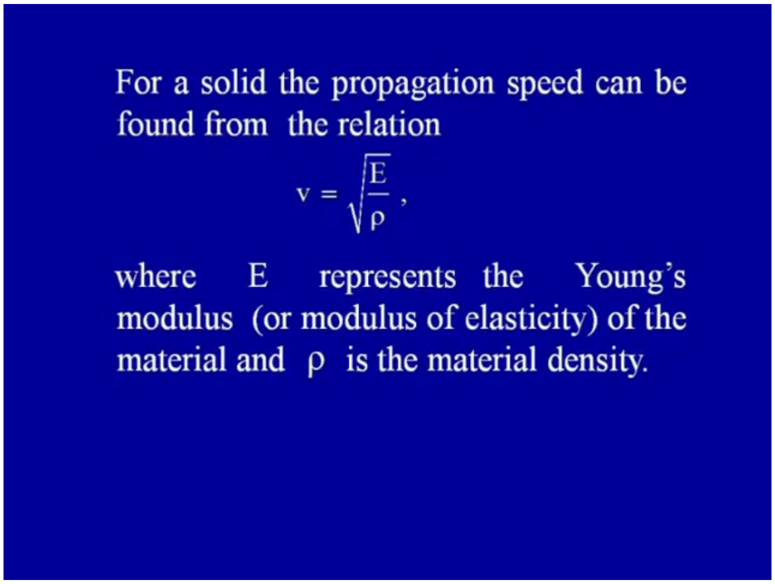

For a solid the propagation speed can be found from the relation v is = square root of E upon Rho where E represents Young's modulus or the modulus of elasticity of the material and Rho is the material density. So, this relation explains why the speed of sound in solids is much higher than what it is in gases or even liquids. This is modulus of elasticity for solids is very large compared to what it is for a gas.

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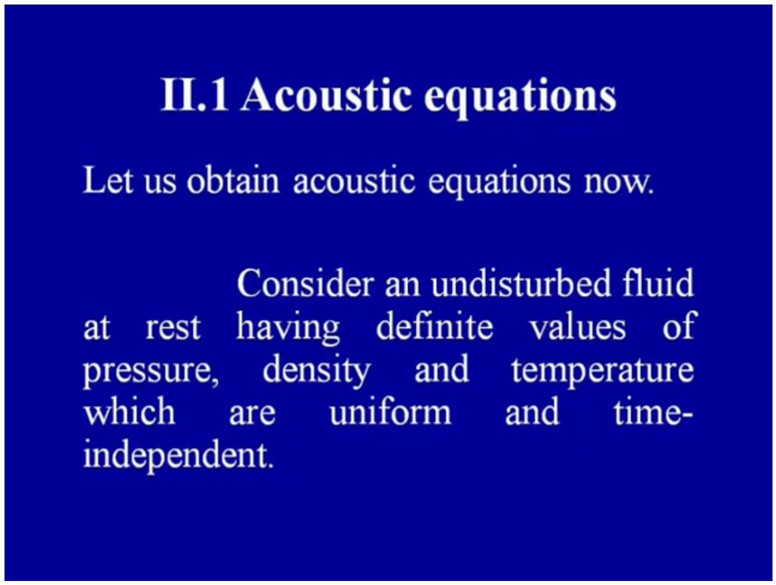

Let us now obtain Acoustic equations. Consider an undisturbed fluid at rest having definite values of pressure, density and temperature which are uniform and time independent. Uniform means these things do not vary from point to point. Time independent means they are steady and are not changing with time.

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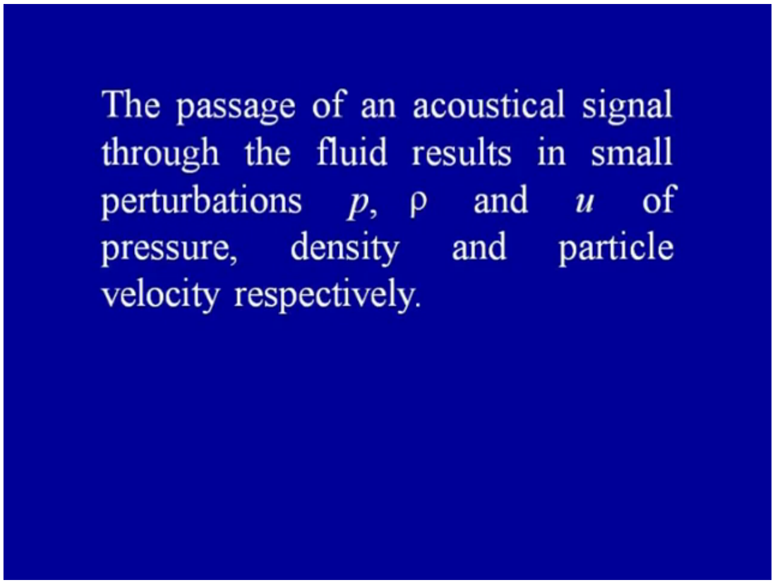

The passage of acoustical signals through the field results in small perturbations small changes in the value of the pressure, in the density and in particle velocity, over the undisturbed values.

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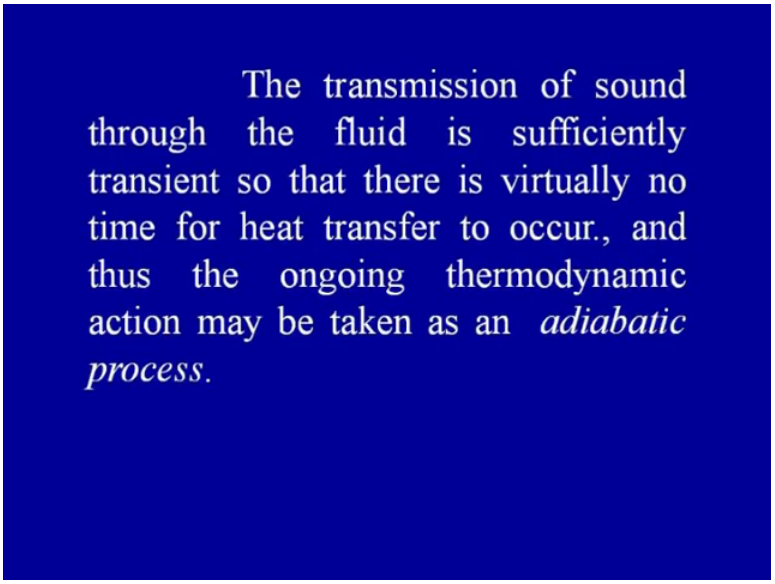

The transmission of sound through the fluid is sufficiently transient so that there is virtually no time for heat transfer to occur. I mean at the point is that these changes are taking place so fast frequencies are pretty high, so there is no time for the heat transfer to occur. And the result is that the ongoing thermodynamic actions during the sound propagation may be taken to be an adiabatic process.

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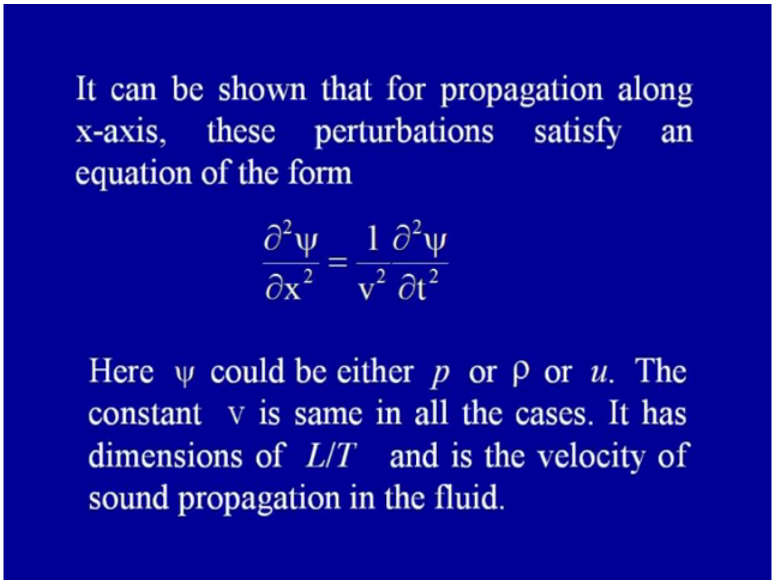

It can be shown that for propagation along the x axis, these perturbations, the perturbations in pressure, perturbations in density, perturbations in particle speed, satisfy an equation of the form del square Psi by del X square is = 1 upon v Square times del 2 Psi by del t square. As I said Psi could be either pressure or density or particle speed. The constant v is same in all these cases it has the dimensions of L by T distance upon time and is the velocity of sound propagation in the fluid.

We shall not derive this equation but I look like to point out the salient features of how it is obtained. Let us consider the continuity equation which is an expression of the conservation of matter for the fellow of a compressible fluid. Similarly consider energy conservation equation in a fluid. This involves the macroscopic kinetic energy and the internal energy of the fluid. These two conservation equations along with the equation of state for the solute they form the basis.

These equations are then solved for small perturbations. First order terms are retained. We can ignore the second order terms and consider the process as adiabatic as pointed out earlier. And that leads to an equation which is given here.

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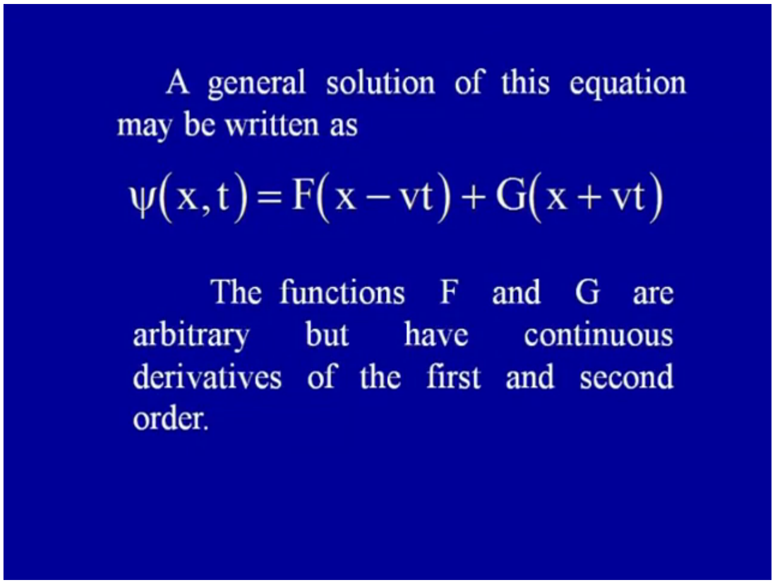

You see, this equation is the second order equation, in time and the variable x. And we know, a partial acoustic original equation like this shall need two initial conditions and two boundary conditions for a well defined solution. But these conditions are really not needed if we are interested in ascertaining the general form of the solution of this equation.

This general solution can be written as Psi of xt. Remember, we are considering propagation along the x axis; so Psi of xt Psi could be as I said earlier it could be particle displacement it could be pressure, it could be density. So = a function F of x - vt and some function G of x + vt. These functions F in G are arbitrary. Arbitrary means that they can be of any form.

But they have to be functions of this combination x - vt or x + vt. And they should have continuous derivatives of the first and second order.

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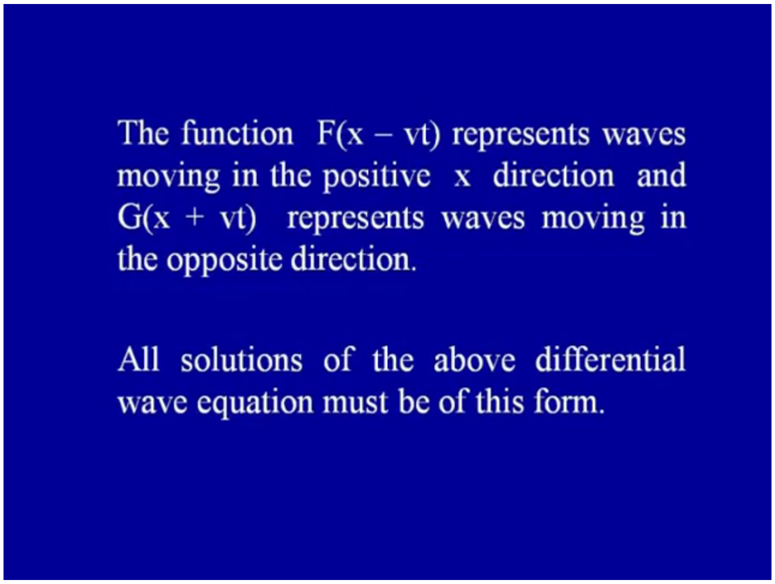

These functions F of x - vt represents waves moving in the positive x direction and similarly the function G of x + vt represents waves moving in the opposite direction. These functions represents wave can be understood like this. Suppose F represents pressure or density as a function of x and t then x and t must increase simultaneously at the rate given by dx by dt = v which is the speed at which the wave is established.

The simultaneous variation of x and t means that as t advances, as t increases, x must also increase. That is the wave is traveling, waves disturbances is moving towards the positive direction of x axis. Similarly for the function G of x + vt as t increases s must decrease simultaneously. Again as I said, simultaneous change means as time advances x must change in the opposite direction.

And the rate determined by, dx by dt = - v. The change in x in the negative direction means the wave disturbance is moving towards the negative direction of x axis. All solutions of the above differential wave equation must be of this form: Function of x - vt or function of x + vt. If there is any other form, that will not satisfy the basic equation.

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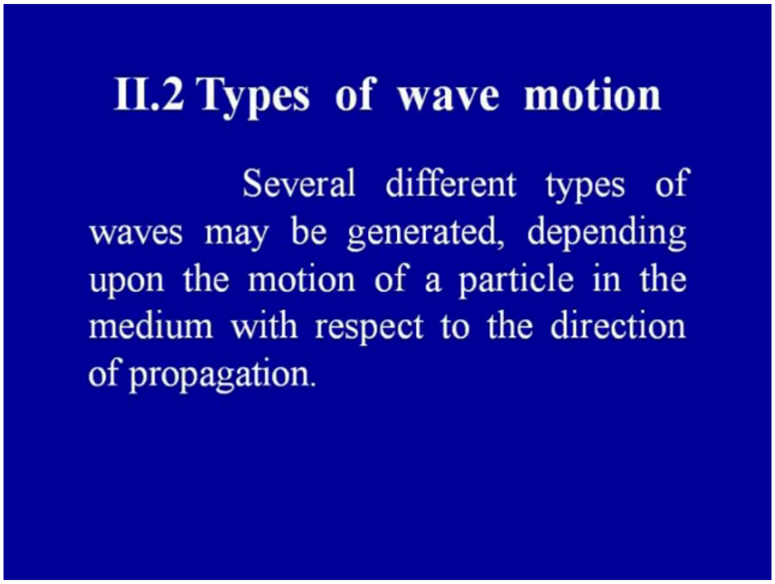

Let us now consider, Types of wave motion. Several different types of waves may be generated, depending upon the motion of a particle in the medium, with respect to the direction of propagation, transverse waves.

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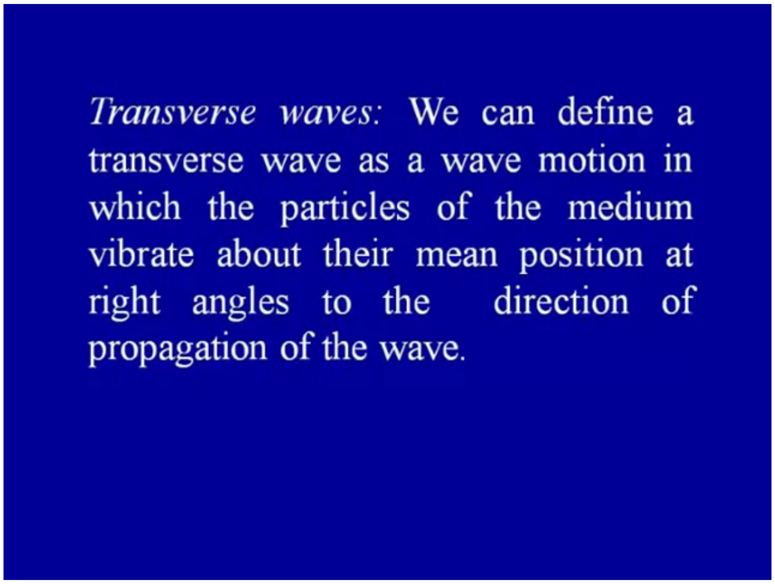

We can define a transverse waves as a wave motion in which the particles of the medium vibrate about their mean position at right angles to the direction of propagation of the wave. The propagation is along the x axis, this means the vibrations are in the transverse plane, in the yz plane. Within the yz plane, these vibrations can have any direction they can also randomly change or change in any fashion.

The wave is polarized the direction can be fixed but always be remaining in the transverse plane. A very common example of transverse waves is the vibrations of a plug district. Sitar spring for example. Or the vibrations of a rod which is clamped at one end; or the vibrations of a tuning fork. All these are very common examples of transverse waves.

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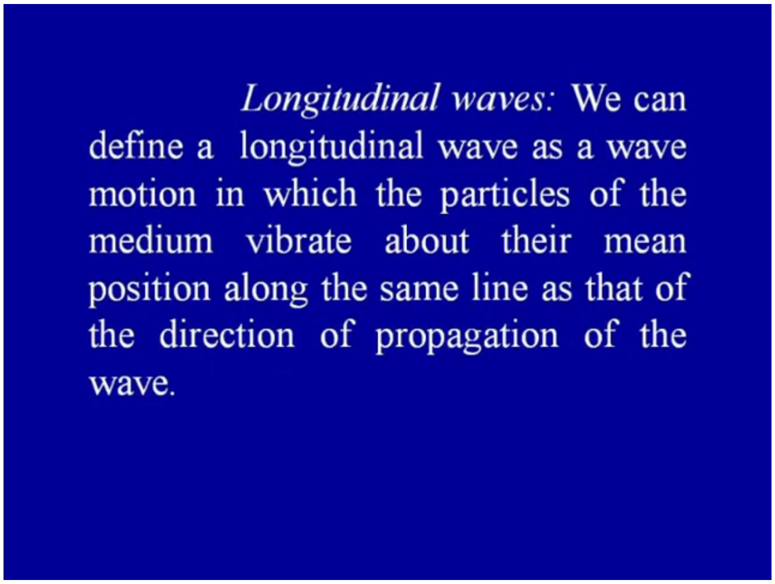

Longitudinal waves: you can define a longitudinal wave as the wave motion in which the particles of the medium vibrate about the mean position again but along the same line as that of the direction of propagation of the waves. The sound waves are principally longitudinal with the results that the particle motion creates alternate compression and rarefaction in the medium. Alternate density increase and density decrease or a pressure increase or a pressure decrease, the sound passes a given point.

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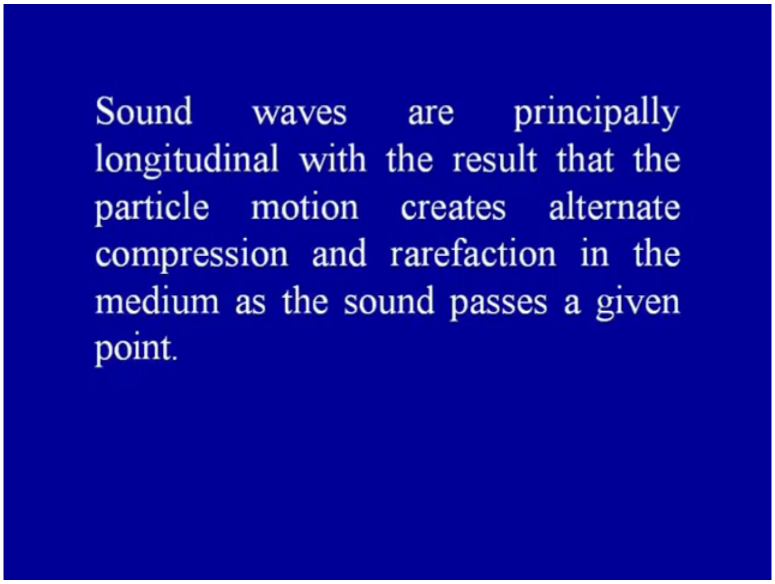

The reason why the sound waves are principally longitudinal is the most of the time we deal with sound waves in air. Or sometimes in water, what are the proportions? You see, these substances do not have a fixed shape. They are not rigid coefficient of rigidity is 0 or the shear coefficient is 0. They cannot support a transverse wave. The only possibility is the longitudinal waves. And that is why most of the time, when we deal with sound waves, we find that they are longitudinal and that thing to be noted.

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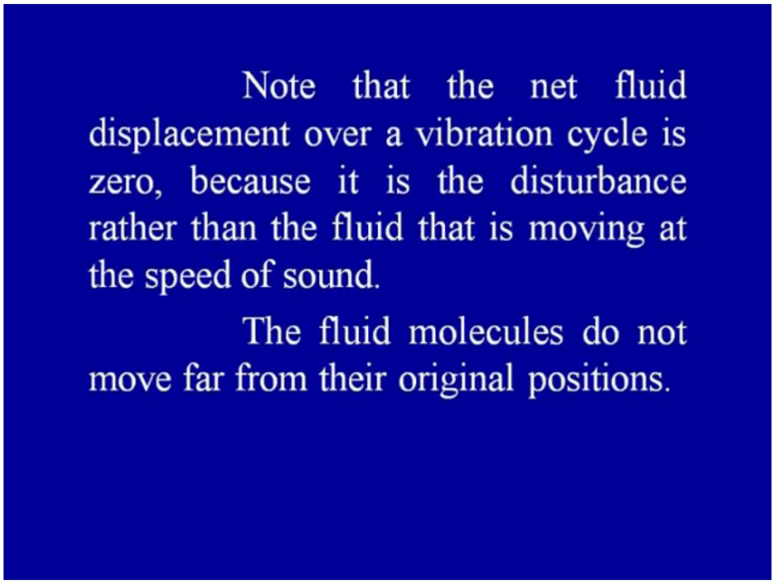

When a sound wave is passing, the net fluid displacement over a vibration cycle is zero, azimuth movement on one side as on the other side, during a vibration. It is the disturbance other than the solute that is moving at the speed of sound. The fluid molecules do not move far from their original positions. Those displacements are very small.

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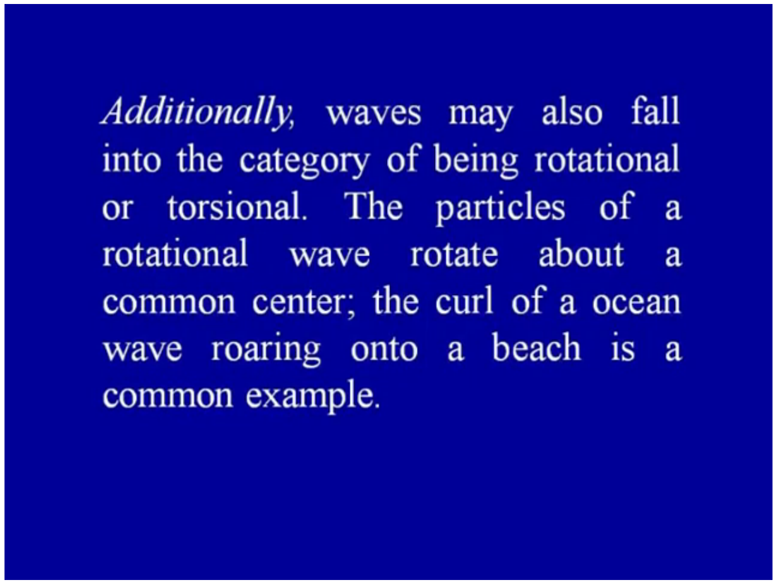

Additionally, waves may also fall into the category of being rotational or torsional waves. The particles of the rotational wave rotate about a common center as the wave advances. The curl of the ocean wave roaring on a beach and to a beach is a very common example.

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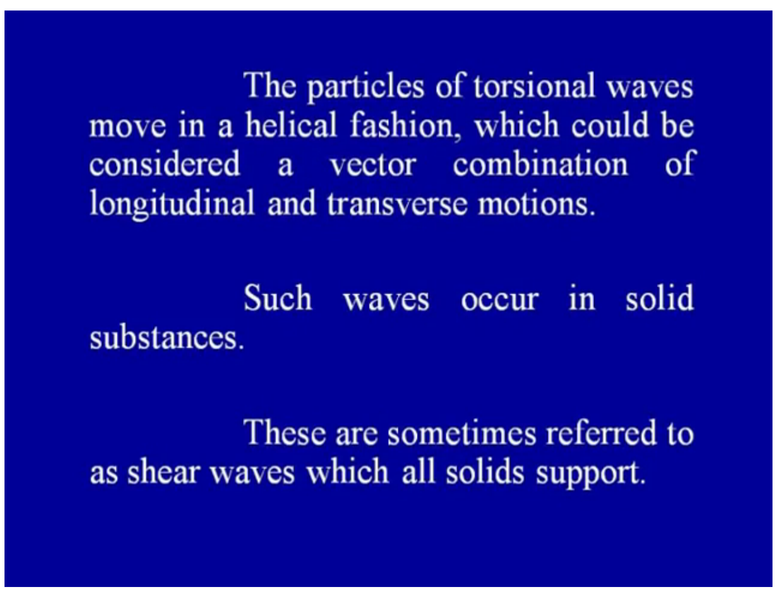

The particles of torsional waves move in a helical fashion which could be considered a vector combination of longitudinal and transverse motions. Such waves will occur in solid substances. Naturally, they cannot occur in gases or in water. These are sometimes referred to as shear waves. The solids have the shear coefficient which is non 0. So, the shear waves with all solids support.

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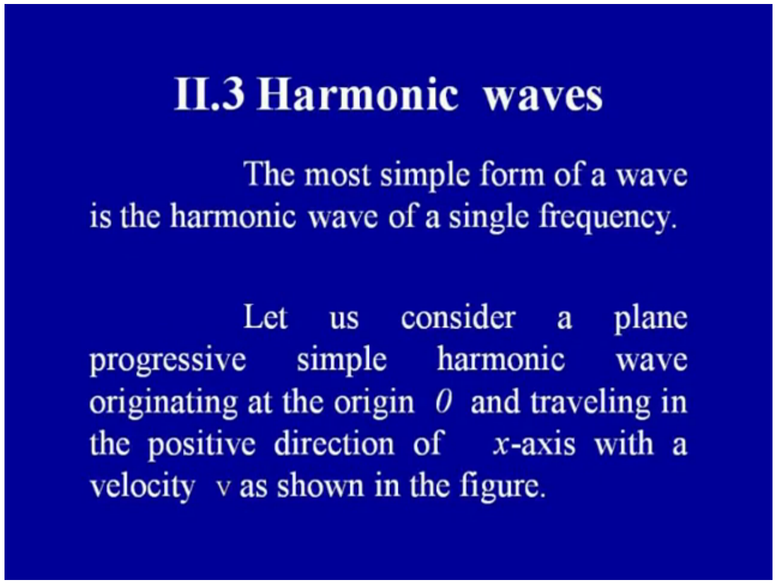

Now, the most simple form of waves is a harmonic wave of a single frequency. You can call it even a monochromatic harmonic wave. Let us consider a plane progressive simple harmonic wave originating at the origin O and traveling in the positive direction of the x axis with the velocity v as shown in the figure.

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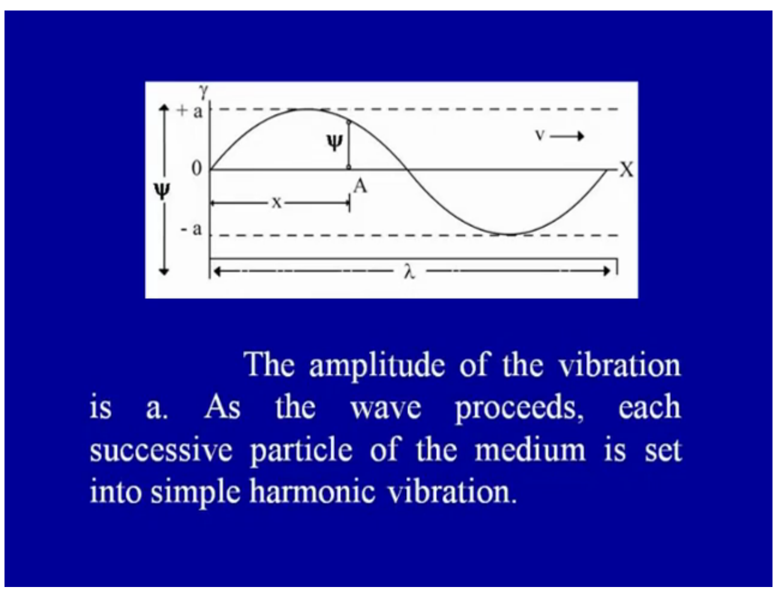

This figure shows the variation of Psi as a function of x at an instant of time t. The amplitude of the vibration is a of the way proceeds, these successive particles of medium is set in two simple harmonic vibration.

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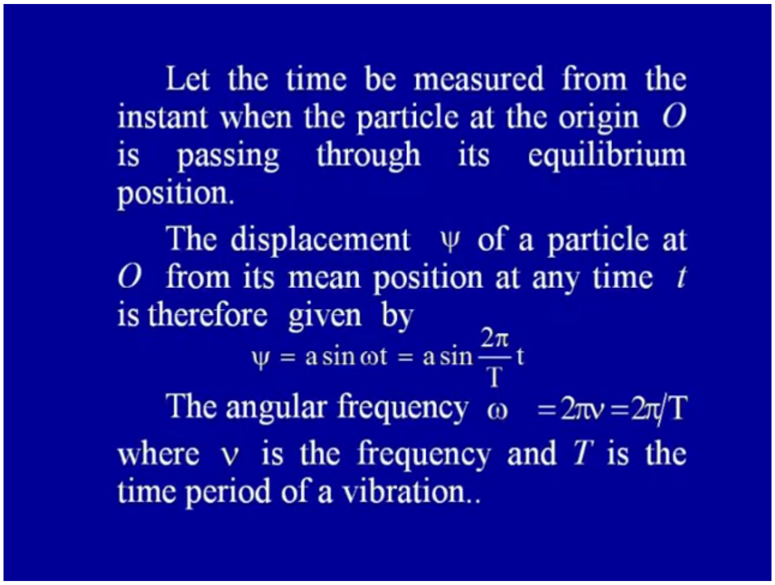

That the time be measured from the instant when the particle had the origin O is passing through its equilibrium position. This will set the initial phase of the vibration. The displacement Psi the particle at O from its mean position at any time t is therefore given by Psi = a sine Omega t which is equal can be written as a sine 2 pi by capital T times t. The angular frequency Omega is = 2 pi Mu which is = 2 pi by capital T, v is the frequency and capital T is the time period of a vibration.

You see, this result for Psi is = a sine Omega t is very standard result for a particle executing simple harmonic motion. Simple harmonic vibratory motion results whenever the situation is such that the restoring force due to the elasticity of the medium is proportional to the displacement.

In a medium and the density changes or when the pressure changes, the force on the particle is again proportional to the change in the density or change in the pressure. The result is we get a simple harmonically varying particle displacement or particle velocity or density changes or pressure changes.

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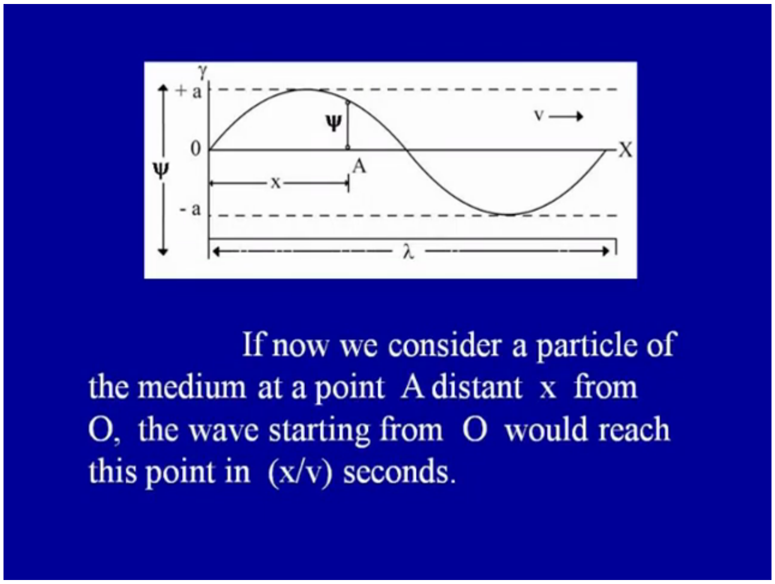

If now, we consider particle of the medium at a point a distant x from the origin O, the wave is starting from O, would reach this point a little later in upon x by v seconds. That is the time taken by the wave.

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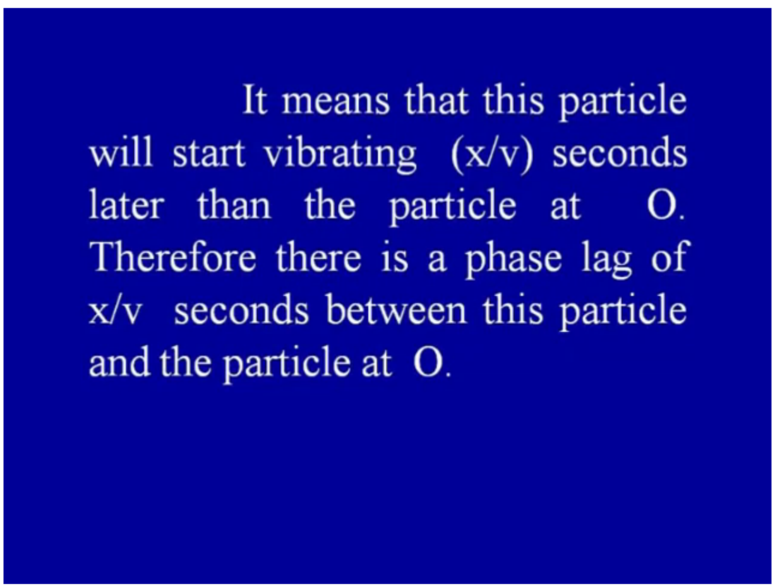

It means that this particle, the particle at a, really start vibrating x by v seconds later than the particle at O. Therefore there is a phase lag of x by v seconds between this particle and the particle at the origin particle at O.

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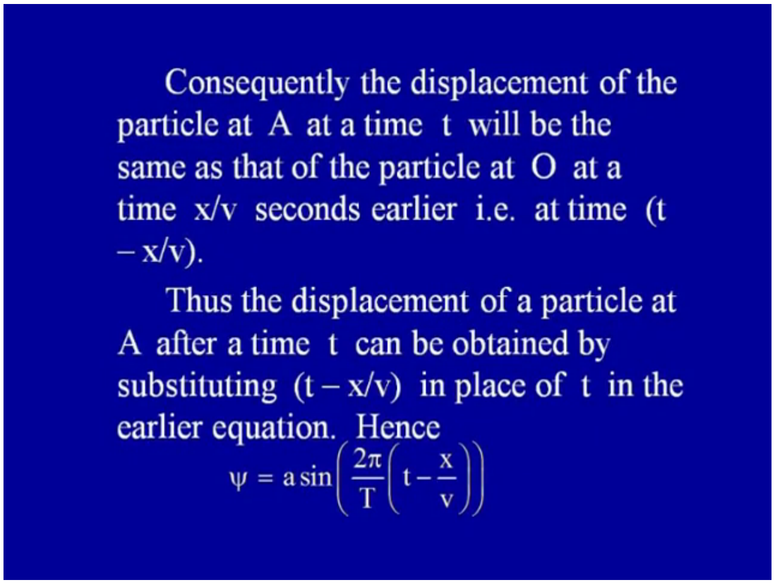

Consequently, the displacement of the particle at a at times t will be the same as that of the particle at O, at a time x by v seconds earlier. That is at time t - x by v. Does the displacement of a particle at a after a time t can be obtained by substituting t - x by v in place of t in the earlier equation. And so we get for the vibrations of this particle whose distance is x from the origin at time t given by Psi is = a times sine of 2 pi by capital T times t - x upon v.

This is the equation of a progressive simple harmonic wave, progressing along the x direction. Let us look at its basic properties, inherent characteristics. As the wave advances, every particle along the path of the wave executes identical, simple harmonic motion. There is a constant lagging of phase for a particle at a distance of x. This phase lag is 2 pi by capital T times x upon v.

If we write Mu for 1 upon T then this phase lag is 2 pi Mu times x upon v or Omega times x upon v. Another thing is, this equation does not contain any y or z. This is the equation of a plane wave. The wave front or the phase fronts or parallel to yz plane. In the yz plane everything is constant. The changes are only along the x axis. So, this is the equation of a plane simple harmonic wave; then, Psi.

If it is a particle displacement, this particle displacement could be along the x axis itself along the direction of propagation. If the wave is longitudinal, has happened for the sound wave within here, this will lead to alternate compressions and rarefactions in the medium. This Psi could also be along the transverse plane, if the wave is a transverse plane as I said, in that case, I mean in the case of a transverse wave, Psi can have any direction in the first plane.

If it is so this Psi can also represent the vibration of a plug of the spring or the vibrations of a tuning fork. And the thing is that the intensity of the wave is proportional to the square of the amplitude a. There are some other factors. But let us not bother about them at this stage. Intensity is proportional to the square of the amplitude a.

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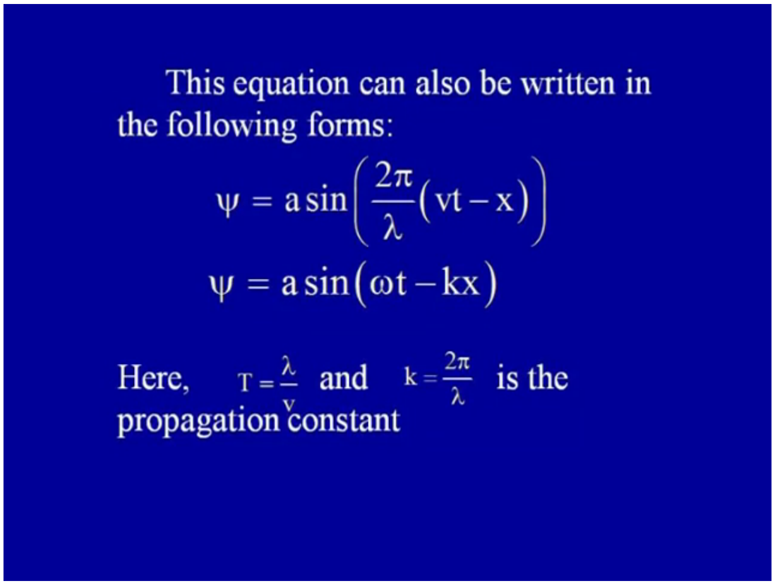

This equation can also be written in the following form Psi = a sine 2 pi by lambda times vt - x; just a question of changing the variables. Or Psi = a sine Omega t - kx here T is = lambda by v and k is 2 pi by lambda, it is the propagation constant. The second form Psi = a sine Omega t is commonly used. So, this is all about simple harmonic plane waves. And with this we come to the end of this lecture. Thank you.